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Averaging is not everything: The saccade global effect weakens with increasing stimulus size

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ABSTRACT

When two elements are presented closely aligned, the average saccade endpoint will generally be located in between these two elements. This ‘global effect’ has been explained in terms of the center of gravity account which states that the saccade endpoint is based on the relative saliency of the different elements in the visual display. In the current study, we tested one of the implications of the center of gravity account: when two elements are presented closely aligned with the same size and the same distance from central fixation, the saccade should land on the intermediate location, irrespective of the stimulus size. To this end, two equally-sized elements were presented simultaneously and participants were required to execute an eye movement to the visual information presented on the display. Results showed that the strongest global effect was observed in the condition with smaller stimuli, whereas the saccade averaging was weaker when larger stimuli were presented. In a second experiment, in which only one element was presented, we observed that the width of the distribution of saccade endpoints is influenced by stimulus size in that the distribution is broader with smaller stimuli. We conclude that perfect saccade averaging is not always the default response by the oculomotor system. There appears to be a tendency to initiate an eye movement towards one of the visual elements, which becomes stronger with increasing stimulus size. This effect might be explained by an increased uncertainty in target localization for smaller stimuli, resulting in a higher probability of the merging of two stimulus representations into one representation.

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1. Introduction

Saccadic eye movements are made to shift the gaze to an object in a visual scene. The exact endpoint of a saccade is based on the pooling of information across the shape of the target object (Cohen et al., 2007; Melcher & Kowler, 1999). Previous studies have shown that saccades directed to a spatially extended object land at a ‘default’ location, near the centroid of the shape (He & Kowler, 1991). The level of precision of eye movements to this default location is comparable to that achieved when a small target point is presented.

In natural visual scenes, saccadic targets are generally spatially extended objects. Also in displays with a small target with one or more neighboring distractors, the endpoint has been found to be positioned at the average location of the display (i.e. ‘the global effect’, for a review see, Van der Stigchel & Nijboer, 2011). Most prominently, studies on the global effect have found that the sac-

cade endpoint is positioned on average at an intermediate location between two elements when these elements are presented in close proximity (Coren & Hoenig, 1972; Findlay, 1982). Although it has been proposed that the global effect only occurs when both elements are presented within 20–30° of angular distance (Ottes, van Gisbergen, & Eggermont, 1984; Walker et al., 1997), recent studies have suggested that the global effect can also be observed for larger distances between the two elements (Van der Stigchel, Mulckhuysse, & Theeuwes, 2009; Van der Stigchel et al., 2011). Saccade averaging is most prominent for saccades with a short latency (Coeffe & O’Regan, 1987; Findlay, 1982; Van der Stigchel & Theeuwes, 2005). In monkeys, it has been shown that the global effect is associated with express saccades, which have an extremely short latency (<100 ms). This global effect for express saccades even occurs when both elements are separated 45° of angular distance (Edelman & Keller, 1998) and is most prominent when no specific instruction was given regarding the saccade target (Chou, Sommer, & Schiller, 1999).

The global effect is generally explained in terms of the ‘center of gravity account’ (Coren & Hoenig, 1972; Findlay, 1982). This account states that the saccade endpoint is based on the relative

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saliency of the different elements in the saccade map: when the distance between two elements is small, the average saliency will be located in between these two elements. Previous studies have provided evidence for the center of gravity account by observing that the saccade lands closer to the largest stimulus (Findlay, 1982), the stimulus with the greatest luminance (Deubel, Wolf, & Hauske, 1984) and closer to the location which is most likely the target location (He & Kowler, 1989). In these situations, the exact endpoint of a saccade therefore reflects the relative saliency of the various elements presented in the visual display.

Because the global effect has recently been applied as a measure of relative saliency in various different domains, like face processing (Bindemann, Scheepers, & Burton, 2009), the interaction between visual working memory and attention (Herwig, Beisert, & Schneider, 2010) and residual visual processing in patients with visual field defects (Van der Stigchel et al., 2010), it is important to fully understand the fundamental aspects of the global effect. To this end, we tested one of the implications of the center of gravity account: when two elements are presented in the visual display with the same size and the same distance from central fixation, the saccade should land on the intermediate location, irrespective of the stimulus size. This prediction is also in line with recent models of oculomotor selection that have accounted for the global effect (Godijn & Theeuwes, 2002; Meeter, Van der Stigchel, & Theeuwes, 2010). Whereas previous studies on the global effect have shown that the saccade endpoint is positioned in the direction of the larger stimulus (Findlay, 1982; Findlay, Brogan, & Wenban-Smith, 1993), the influence of stimulus size when both elements are equally sized is unknown. Larger stimuli activate a broader range of neurons in the oculomotor system than smaller stimuli (Goldberg & Wurtz, 1972) and might therefore be associated with less uncertainty in target localization than smaller stimuli. A lower uncertainty might then result in a lower probability of stimulus representations being averaged than when uncertainty is high. If this reasoning is correct, presenting two large stimuli will result in a smaller global effect than when two small stimuli are presented.

In the current experiment, two equally sized stimuli were presented simultaneously. The size of both stimuli was varied between trials. To investigate the averaging of saccades without any bias to select one of the two presented elements as the target location of the eye movement, a task was employed in which participants were required to make an eye movement as fast as possible to the visual information presented on the screen. Similar to certain previous studies in human on the global effect (Deubel, Wolf, & Hauske, 1984; Findlay, 1982; Ottens, van Gisbergen, & Eggermont, 1984) there was therefore no specific target element.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve naive participants (20–62 years old; 5 male), all naive to the purpose of the experiment, participated in the experiment. All had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the study in accordance with the guidelines of the Helsinki Declaration.

2.1.2. Apparatus

Participants performed the experiment in a sound-attenuated setting, viewing a display monitor from a distance of 72 cm. Eye movements were recorded by an Eyelink 1000 system (desktop system; SR Research Ltd., Canada), an infra-red video-based eye tracker that has a 1000 Hz temporal resolution and a spatial reso-

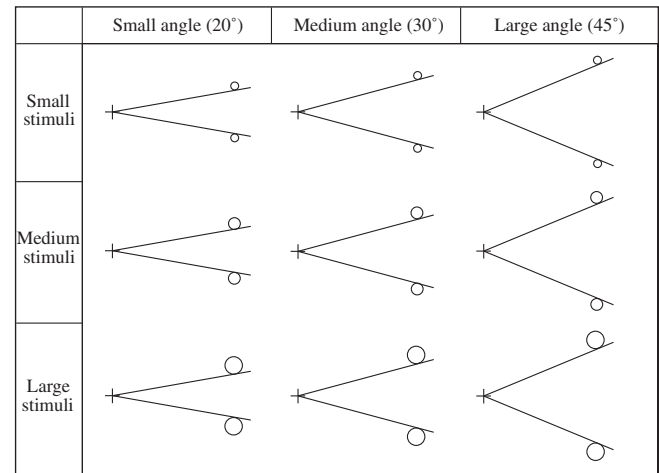


Fig. 1. The different conditions of the present experiment. The size of two similar-sized circles was either .50°, .75°, or 1.12°. The distance between the two inner edges of the circles was either 20°, 30°, or 45°.

lution of 0.01°. The participant's head was stabilized with a chin rest, and an infrared remote tracking system compensated for any residual head motion. The left eye was monitored. An eye movement was considered a saccade when either eye velocity exceeded 35°/s or eye acceleration exceeded 9500°/s².

2.1.3. Stimuli and procedure

Participants viewed a display containing a gray cross (1.1 × 1.1°) on a black background in the center of the display, which was used as fixation point. The fixation point was removed after a random interval of 500–1000 ms. Subsequently, two gray filled circles were presented simultaneously. Both circles had the same size which could either be .50°, .75°, or 1.12°. The distance between the two inner edges of the circles could either be 20°, 30°, or 45°. To scale the possible sizes of the circles with the possible distances, we applied the same ratio (1:1.5:2.25) for the possible sizes (.50°, .75°, or 1.12°) as for the possible distances (20°, 30°, or 45°). The different conditions are represented in Fig. 1.

The two circles were presented in the same quadrant and were positioned around four principal axes (45°, 135°, 225°, 315°). Previous studies on the global effect also presented the stimuli in an oblique direction (He & Kowler, 1989; Ottens, van Gisbergen, & Eggermont, 1984). Each stimulus appeared on either side of the axis at equal distance from the axis. The distance from the central fixation point to the stimuli was 8.3°. The target display was presented for 1200 ms. Afterwards all objects were removed from the display.

Participants were instructed to fixate on the central fixation cross and to move their eyes to the stimuli on the monitor as quickly as possible. Each session started with a nine-point grid calibration procedure. In addition, simultaneously fixating the central fixation point and pressing the space bar recalibrated the system by zeroing the offset of the measuring device at the start of each trial. The sequence of trials was randomized. The experiment consisted of 432 experimental trials and 36 practice trials.

2.2. Data analysis

2.2.1. Saccade endpoint

As we compared the saccadic landing position between conditions in which the distance between the two stimuli differed, we needed a measure that could account for these differences. Saccadic landing position was therefore computed as a *proportion* of the

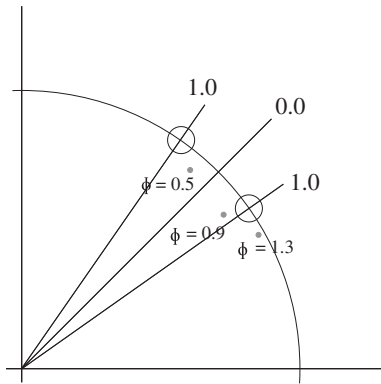


Fig. 2. Saccadic landing position was computed as a proportion of the angle between both stimuli. The axis around which the stimuli were positioned, representing the geometric midpoint between the stimuli, was used as a null-reference. Three possible endpoints are presented with their associated score.

angle between both stimuli. The axis around which the stimuli were positioned (the geometric midpoint between the stimuli) was used as a null-reference (see Fig. 2). This means that saccades which landed on the axis were defined as having a deviation score of zero ($\Phi = 0.0$). Because neither of the two stimuli was the designated target location, we defined the landing positions deviating towards either of the two stimuli as positive. The location of one of the stimuli is equivalent to a deviation score of plus one ($\Phi = 1.0$). A score higher than one means that the saccade did not land in between the two stimuli.

Eye movements sometimes portrayed a small drift ($\leq 1^\circ$) from fixation at the start of the saccade. Since this influences the relative position of the stimuli in relation to the start of the saccade, the deviation score (Φ) was calculated relative to the actual starting point of the saccade.

If a landing position in any of the conditions was further than two and a half standard deviations away from the average landing position per condition of the participant, both in amplitude and deviation score, the trial was marked as an outlier and removed from the analysis.

As mentioned, we defined the landing positions deviating towards either of the two stimuli as positive. To be able to collapse the two stimulus locations, an analysis was run to ensure that there was no tendency for the saccade to land on either the uppermost or lowermost stimulus in each quadrant. Therefore, it was computed using a (non-parametric) Wilcoxon test whether the average landing position, when not collapsed, was different from zero. If different from zero, this would indicate that there was a tendency for the endpoint to be positioned in the direction of either the uppermost or lowermost stimulus. The Wilcoxon test was not significant ($p = 0.11$), indicating that this tendency was absent. As previous studies have indicated that there might be a bias to make saccades in the horizontal directions (e.g. Tatler & Vincent, 2009), we performed the same test to investigate whether there was a tendency for the saccade to land on the more horizontal target versus the more vertical target. The Wilcoxon test was not significant ($p = 0.18$), indicating that this bias was absent.

There was no effect of quadrant on saccade averaging as revealed by a Friedman ANOVA ($X^2 = 5.1$; $p = 0.16$). Therefore, landing positions for all four quadrants were collapsed to one quadrant (upper right). All reported effects below were observed independent of the way of collapsing.

To investigate to what extent the different conditions evoked a global effect, we fitted a polynomial for each condition using the EzyFit Toolbox for Matlab. Because the best fits were obtained with a sixth degree polynomial, we adopted this degree for our analyses. Bimodal fits were constrained such that each peak is centered on

the location of a target. Unimodal fits were constrained such that the peak is at the midpoint between the two stimuli. To compute which conditions showed a unimodal distribution and which conditions a bimodal distribution, we calculated the sum of squares for each condition with respect to the fit observed in the strongest unimodal condition and the strongest bimodal condition. The sum of squares is the sum of squared residuals, a residual being the difference between the observed value and the fitted value.

2.2.2. Saccade latency

Saccade latency was defined as the interval between target onset and the initiation of the saccadic eye movement. Trials with a saccadic latency lower than 80 ms (anticipatory saccades) or higher than 450 ms were excluded (too slow saccades). All trials with a latency of more than two and a half standard deviations away from the participants' mean were excluded from the analysis, as they were regarded as outliers. For saccade latencies, an ANOVA was run with stimulus size (small: $.50^\circ$, medium: $.75^\circ$, large: 1.12°) and stimulus distance (small: 20° , medium: 30° , large: 45°) as factors.

3. Results

The exclusion criteria led to a loss of 7.71% of trials.

3.1. Landing position

Fig. 3 displays the raw distribution of landing positions for all nine conditions. It can easily be seen that the largest global effect was observed in the condition with a small stimulus size and a small stimulus distance, whereas the smallest global effect was observed in the condition with a large stimulus size and a large stimulus distance. The sum of squares for each condition was therefore computed with respect to the fit observed in the strongest unimodal condition (the condition with both a small stimulus size and stimulus distance) and the strongest bimodal condition (the condition with both a large stimulus size and stimulus distance).

The sum of squares can be observed in Table 1. From this table, it can be concluded that in all conditions in which the stimulus size was large, the fit with a bimodal distribution was better than with a unimodal distribution. A bimodal distribution indicates that the global effect was not the average response. In almost all other conditions, the fit with the unimodal distribution was better. In the condition in which the stimulus distance was large and the stimulus size medium, the fit was about equal for both distributions.

These results are also reflected in the individual analyses illustrated in Table 2. Here, we computed for each condition the number of participants for which the bimodal fit was better than the unimodal fit. When the stimulus size was large, there were more participants for which the bimodal fit was better than the unimodal fit. The transition from unimodal to bimodal distributions with increasing stimulus size is already apparent on the level of the individual participants. Fig. 4 shows, for two participants, the plots of the raw distribution of landing positions for the different conditions. On the basis of these findings, it can be concluded that the stimulus size was crucial in determining whether a unimodal distribution was observed. To illustrate these findings, we plotted all saccade endpoints for one quadrant for the three different stimulus size conditions. Fig. 5 clearly shows that saccade averaging is stronger for the smaller stimuli compared to the larger stimuli.

3.2. Saccade latency

We found a main effect of stimulus size ($F(2,22) = 11.532$; $p < 0.001$). Saccade latencies in the condition with a small stimulus

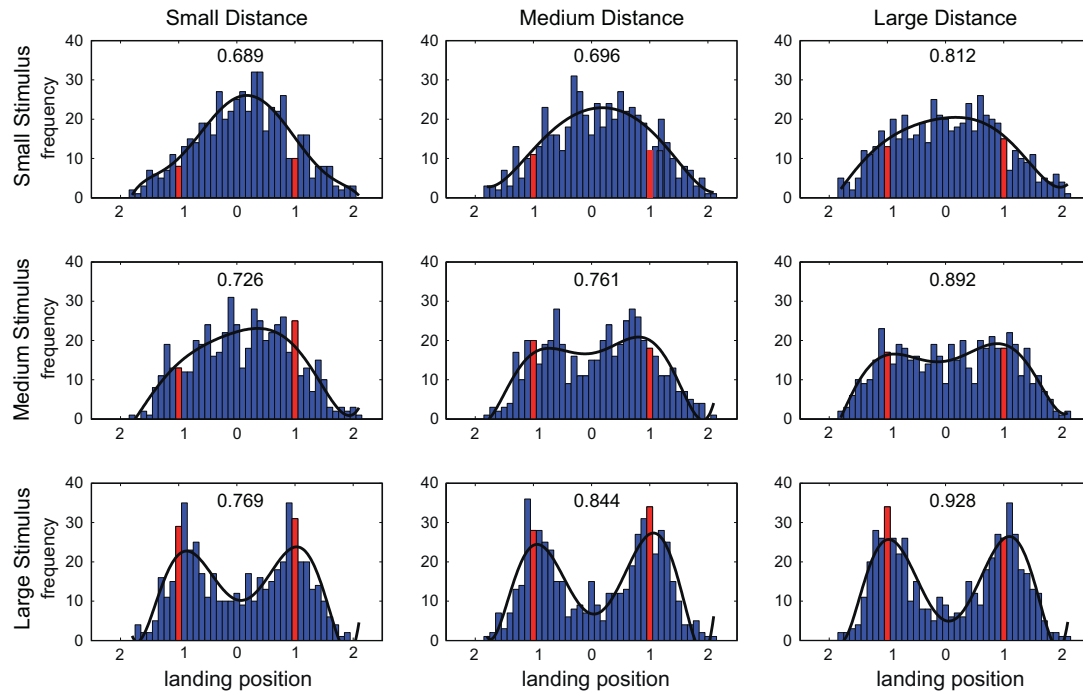


Fig. 3. A frequency plot for all nine conditions. The stimuli are presented at the location with value 1. For each condition, the mean value of the saccadic landing position is given.

Table 1

Sum of squares for all conditions with respect to a unimodal and a bimodal distribution.

Condition	Unimodal	Bimodal
Small distance/small size	443	5643
Medium distance/small size	591	3929
Large distance/small size	736	3303
Small distance/medium size	841	3582
Medium distance/medium size	1584	2411
Large distance/medium size	1811	1597
Small distance/large size	3462	1300
Medium distance/large size	5096	887
Large distance/large size	5882	586

Table 2

The number of participants for which the bimodal fit was better than the unimodal fit.

Condition	Small distance	Medium distance	Large distance	Average
Small size	1	3	4	2.7
Medium size	4	5	6	5.0
Large size	3	9	11	7.7
Average	2.7	5.7	7.0	

were significantly longer (mean = 177 ms; st. dev. = 18 ms) than in the condition with medium stimuli (mean = 174 ms; st. dev. = 19 ms; $t(11) = 3.19$; $p < 0.01$) and in the condition with large stimuli (mean = 172 ms; st. dev. = 19 ms; $t(11) = 4.96$; $p < 0.01$).

There was a main effect of stimulus distance ($F(2,22) = 8.617$; $p < 0.01$). Saccade latencies in the condition with small stimulus distance were significantly shorter (mean = 172 ms; st. dev. = 19 ms) than in the condition with medium stimulus distance (mean = 174 ms; st. dev. = 19 ms; $t(11) = 2.34$; $p < 0.05$) and in the condition with large stimulus distance (mean = 177 ms; st. dev. = 20 ms; $t(11) = 3.32$; $p < 0.01$). Furthermore, saccade latencies in the condition with medium stimulus distance were significantly

shorter than in response to stimuli with a large distance ($t(11) = 2.53$; $p < 0.03$).

No significant interaction between stimulus size and stimulus distance was observed ($F(4,44) = 2.308$; $p = 0.07$).

It has to be noted that, even though significant, the differences in saccade latency are quite small (maximally 5 ms).

3.3. The effect of saccade latency on saccade landing position

As it is known that the global effect can be influenced by the saccade latency of the eye movement (Coeffe & O'Regan, 1987; Findlay, 1982; Van der Stigchel & Theeuwes, 2005), we investigated whether the saccade landing position was modulated by saccade latency, by computing a correlation between saccade latency and the landing position for all trials recorded. This computation was performed for each of the nine conditions separately. None of the correlations was significant (highest correlation was $r = 0.07$; $p = 0.11$ for the condition with a medium stimulus distance and a small stimulus size). When performing this analysis for the 12 participants individually, there was only one condition for which half of the participants showed a significant correlation. For the other eight conditions, the correlation was only statistically significant for at most 3 of the 12 participants (see Table 3). It can therefore be concluded that the landing position of the eye movement was generally not modulated by saccade latency.

The question then arises whether the eye movements landing in between the two target locations have a different latency than the eye movements that land on the target location. To this end, an analysis was performed in which the saccade latency for eye movements with a landing position between 0 and 0.5 (landing close to the midpoint between both stimuli) was compared to the saccade latency for eye movements with a landing position between 0.5 and 1.5 (landing close to one of the target locations). A t -test was performed for each of the nine conditions. One participant had no eye movements landing in one of the two areas for one condition and was therefore excluded in the analysis of this condition.

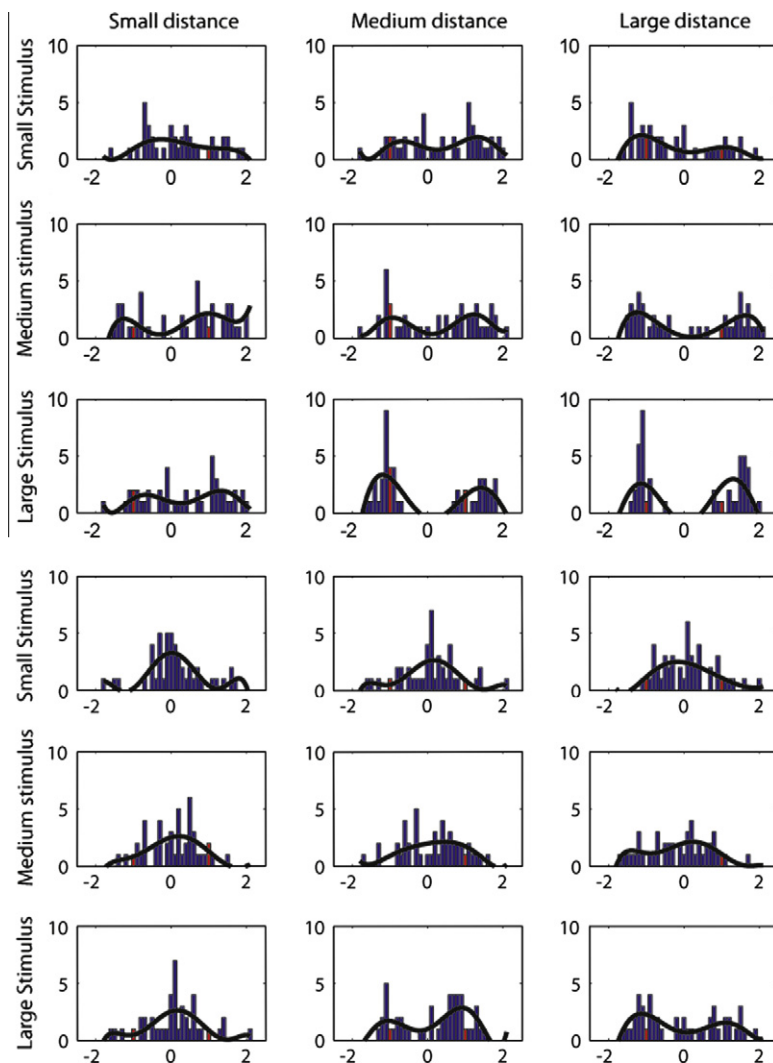


Fig. 4. The plots of the raw distribution of landing positions for the different conditions for two participants.

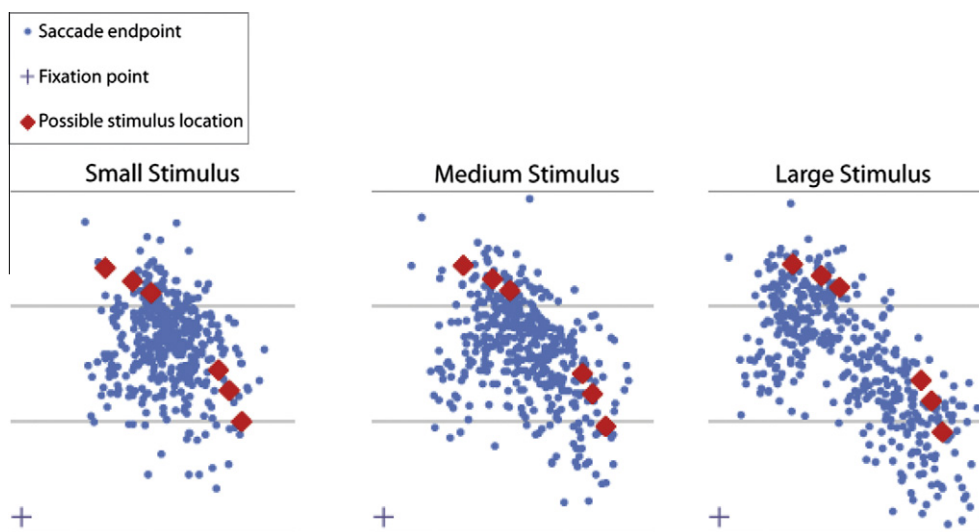


Fig. 5. Saccade endpoints in one quadrant plotted for the three stimulus size conditions. These data are collapsed for the three stimulus distance conditions.

For none of the nine conditions, this difference was significant (p 's > 0.05), again pointing to an absence of influence of saccade latency on saccade endpoint in the current experiment. This also be-

came apparent when examining this analysis for the 12 individual participants: for all conditions, the number of participants with a significant difference was less than 2 (see Table 4).

Table 3

The number of participants for which the correlation between saccade latency and landing position was significant (the number of positive and negative significant correlations are indicated by '+' and '–', respectively).

Condition	Small distance	Medium distance	Large distance	Average
Small size	3 (2+/1–)	2 (1+/1–)	1 (1+/0–)	2.0 (1.3+/0.7–)
Medium size	6 (5+/1–)	3 (3+/0–)	0 (0+/0–)	3.0 (2.7+/0.3–)
Large size	3 (0+/3–)	2 (0+/2–)	1 (0+/1–)	2.0 (0.0+/2.0–)
Average	4.0 (2.3+/1.7–)	2.3 (1.3+/1.0–)	0.7 (0.3+/0.3–)	

Table 4

The number of participants for which the difference in latency between saccades landing close to the midpoint between the stimuli and saccades landing close to one of the target locations was significant.

Condition	Small distance	Medium distance	Large distance	Average
Small size	1	2	1	1.3
Medium size	2	1	2	1.7
Large size	2	2	0	1.3
Average	1.7	1.7	1.0	

4. Discussion Experiment 1

The results of Experiment 1 show that the size of the global effect is dependent on the size of the two stimuli: saccade averaging was smaller for larger stimuli than for smaller stimuli. These results are not in line with the prediction of the center of gravity account, but seem to implicate that larger stimuli might be associated with less uncertainty in target localization than smaller stimuli. In Experiment 1, however, there was no condition in which one stimulus was presented. Therefore, there was no baseline of the variability in endpoints. To investigate whether the reported effects of stimulus size on the global effect can be explained by differences in the baseline variability in saccade endpoints, a second experiment was run in which only one stimulus was presented. In each trial, the size of the stimulus was one of the three possible stimulus sizes used in Experiment 1.

5. Experiment 2

5.1. Methods

5.1.1. Participants

Seven naive participants (average age 31; std. = 8.12; 5 male) participated in this experiment. Three of the participants were also included in Experiment 1.

5.1.2. Apparatus, stimuli and procedure, data analysis

The present experiment differed from Experiment 1 in the number of elements presented and the location of the stimuli. In this experiment, only one stimulus was presented. The circle was either .50°, .75°, or 1.12°. The circle was positioned on one of four

principal axes (45°, 135°, 225°, 315°) on the 'average' location in between the two possible stimulus locations of Experiment 1.

The experiment consisted of 144 experimental trials with a break after each block of 12 trials and 12 practice trials. With respect to data analysis, the same requirements were used as in Experiment 1.

6. Results and discussion

The exclusion criteria led to a loss of 11.0% of trials.

6.1. Landing position

Fig. 6 shows the distributions of the endpoints for each of the three conditions. Interestingly, stimulus size influenced the distribution of saccade endpoints in this experiment. The distribution for the condition in which the stimulus was small was broader compared to the condition in which the stimulus was large. This was supported by the finding that the frequency of trials falling directly on the center of the stimulus (values between –1 and +1) were much higher in the condition with a large stimulus (124 trials) than in the condition with a medium stimulus size (97 trials) and the condition with a small stimulus size (76 trials).

Furthermore, we investigated how the endpoint distributions of Experiment 1 would have looked if no averaging had occurred in that experiment. To this end, we plotted for each condition the endpoint distributions obtained in the current experiment on the locations of both possible stimulus locations of Experiment 1. Results showed that the obtained distributions of the endpoints were bimodal in each of the three conditions. This indicates that the averaging observed in Experiment 1 (i.e. a unimodal distribution for smaller stimuli) cannot solely be explained by a difference in the baseline variability of saccade endpoints for the different stimulus sizes. If this would have been the case, unimodal distributions should have been observed, similar to those obtained in Experiment 1.

6.2. Saccade latency

We found a main effect of stimulus size ($F(2,22) = 11.829$; $p < 0.01$). Saccade latencies in the condition with a large stimulus were significantly shorter (mean = 164 ms; st. dev. = 14 ms) than

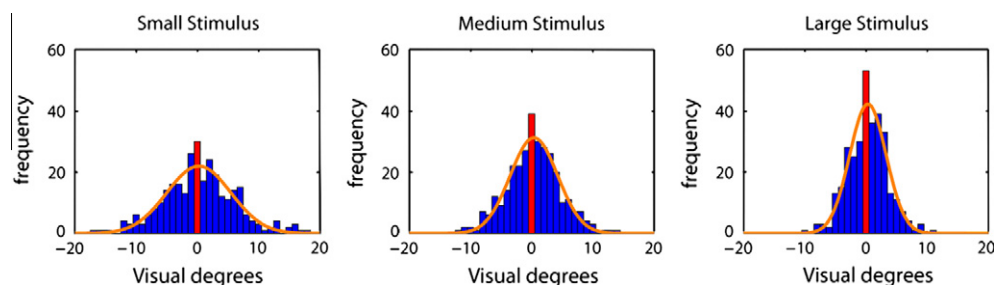


Fig. 6. Frequency plots of the endpoints observed in Experiment 2.

in the condition with a medium stimulus (mean = 170 ms; st. dev. = 17 ms; $t(6) = 3.33$; $p < 0.02$) and in the condition with a small stimulus (mean = 174 ms; st. dev. = 16 ms; $t(6) = 4.92$; $p < 0.01$).

These results provide evidence for the idea that stimulus localization is less accurate for a smaller stimulus compared to a larger stimulus. Although the averaging observed in Experiment 1 cannot solely be explained by a difference in the baseline variability of saccade endpoints for the different stimulus sizes, the distribution for the condition in which the stimulus was small was broader compared to the condition in which the stimulus was large. Furthermore, saccade latencies were shorter for the larger stimulus compared to the smaller stimulus, which is in line with the idea that stimulus localization is less accurate for a smaller stimulus compared to a larger stimulus.

7. Discussion

The aim of the current study was to test one of the implications of the center of gravity account: when two elements are presented in a visual display with the same size, the saccade should land on the intermediate location, irrespective of the size of both stimuli. The results of the present study were not in line with this prediction: the size of the global effect was modulated by the size of the two visual stimuli. The strongest global effect was observed in the condition with the smaller stimuli, while the global effect was weaker when larger stimuli were presented. Although the saccade should land on the intermediate locations of the two targets in all conditions, the saccade landed more towards one of the two elements when these elements were large.

These results are inconsistent with current models of the global effect (Godijn & Theeuwes, 2002; Meeter, Van der Stigchel, & Theeuwes, 2010). These models account for the global effect by assuming that two visual signals are integrated in a common saccade map and are merged into one single peak. Because this single peak has the highest activity in the saccade map, this is the location towards which the saccade is initiated. These models would therefore predict that the highest peak in the saccade map will be positioned in between two equally-sized stimuli, irrespective of the size of the stimuli. This is not what we observed in the present experiment.

When examining the distributions of landing positions in detail, it was found that the stimulus size determined whether a unimodal or a bimodal distribution was observed. When the stimulus size was small or medium, endpoint distributions were unimodal, indicating that the average response in these conditions was directed at the location in between the two stimuli (global effect). When the stimulus size was large, the endpoint distribution was bimodal, indicating that the endpoint was generally allocated at one of the two stimulus positions. The global effect was therefore not the dominant response when the stimulus size was large. The influence of the stimulus distance on the endpoint distribution was less strong.

Because the global effect was influenced by the size of both stimuli, perfect saccade averaging is not the default response by the oculomotor system. In this experiment, there was no a priori reason to saccade to one of the two elements: as there was no specific target element, both elements had the same status in the oculomotor selection process. But even though there was no task instruction to saccade to one of the elements, there was a tendency to initiate an eye movement in the direction of a visual element, which increased with increasing stimulus size. The results of Experiment 2 might provide an explanation for this observation. In this experiment, in which only one element was presented, it was observed that the width of the endpoint distribution varies with stimulus size. The distribution was broader for smaller stim-

uli than for larger stimuli. Although the averaging observed in Experiment 1 could not solely be explained by a difference in the baseline variability of saccade endpoints for the different stimulus sizes, the results of Experiment 2 do show that stimulus localization for a smaller stimulus is less accurate compared to a larger stimulus. This is also consistent with the finding that latencies were shorter for eye movements to larger stimuli than to smaller stimuli. As it is known that uncertainty in the localization of a stimulus is a major source of explaining the variability in saccade endpoints (van Beers, 2007), the stronger averaging for smaller stimuli might be explained by a higher degree of uncertainty in target localization for smaller stimuli than for larger stimuli. When uncertainty is high, there might be a higher probability of stimulus representations being averaged than when uncertainty is low. A high probability of an averaging stimulus representations will then result in more averaging saccades and therefore a stronger global effect. Interestingly, the size of the largest stimulus in the current experiment was already quite small (1.12°). Although this hypothesis remains speculative and should be tested in future experiments, we propose that the center of gravity account should be extended with a bias towards one of the elements presented in the visual display, which is influenced by the degree of certainty of target localization.

We also investigated the extent to which saccade averaging is influenced by the distance between the two elements. Results showed that the global effect was strongest when two elements were presented closely aligned. Contrary to the idea that saccade averaging only occurs when both elements are presented within $20\text{--}30^\circ$ of angular distance (Ottes, van Gisbergen, & Eggermont, 1984; Walker et al., 1997), there was still a shift of saccade endpoint towards the intermediate location when the two elements were presented outside this region. This effect was modulated by the size of both stimuli: only when the two elements were large, no shift of saccade endpoint was observed when the two elements were presented far apart. Therefore, with smaller stimuli, a small but consistent global effect might still be observed for the average landing point when the distance between the two stimuli is larger than 30° . In this situation, uncertainty in the localization of a stimulus might still be high because of the relatively small size of the stimulus.

In the current experiment, the global effect was not, or at most weakly, modulated by saccade latency. This appears to be inconsistent with previous observations that saccade averaging is strongest for short latencies, because these are predominantly executed on the basis of bottom-up, visual information (Coeffe & O'Regan, 1987; Findlay, 1982; Van der Stigchel & Theeuwes, 2005). This inconsistency might be explained by the fact that our data samples only a part of the possible saccade latency range. Indeed, saccade latencies for all conditions were shorter than 180 ms and few express saccades were observed (<3%). Furthermore, saccade latencies for saccades to one of the two elements had the same latency as averaging saccades. There are two possible explanations for this restricted latency range. Firstly, this might be caused by the predictability of the task. There were always two stimuli presented on one of four possible locations and there was no variable offset of the fixation point (a variable offset of the fixation point results in variability in saccade latencies, McSorley, Haggard, & Walker, 2006). Secondly, there was no explicit task instruction to saccade to one of the two elements. Top-down processes were therefore not necessary to correctly perform the task. The lack of a strong top-down component might have resulted in a somewhat restricted latency range. A more variable range of saccade latencies might result in the expected modulation of saccade averaging by saccade latency.

In summary, the present study extends the center of gravity account by showing that stimulus size is an important factor in

determining the size of the global effect. Perfect saccade averaging does not seem to be the default response by the oculomotor system, but is mediated by the degree in which both target elements can be localized.

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